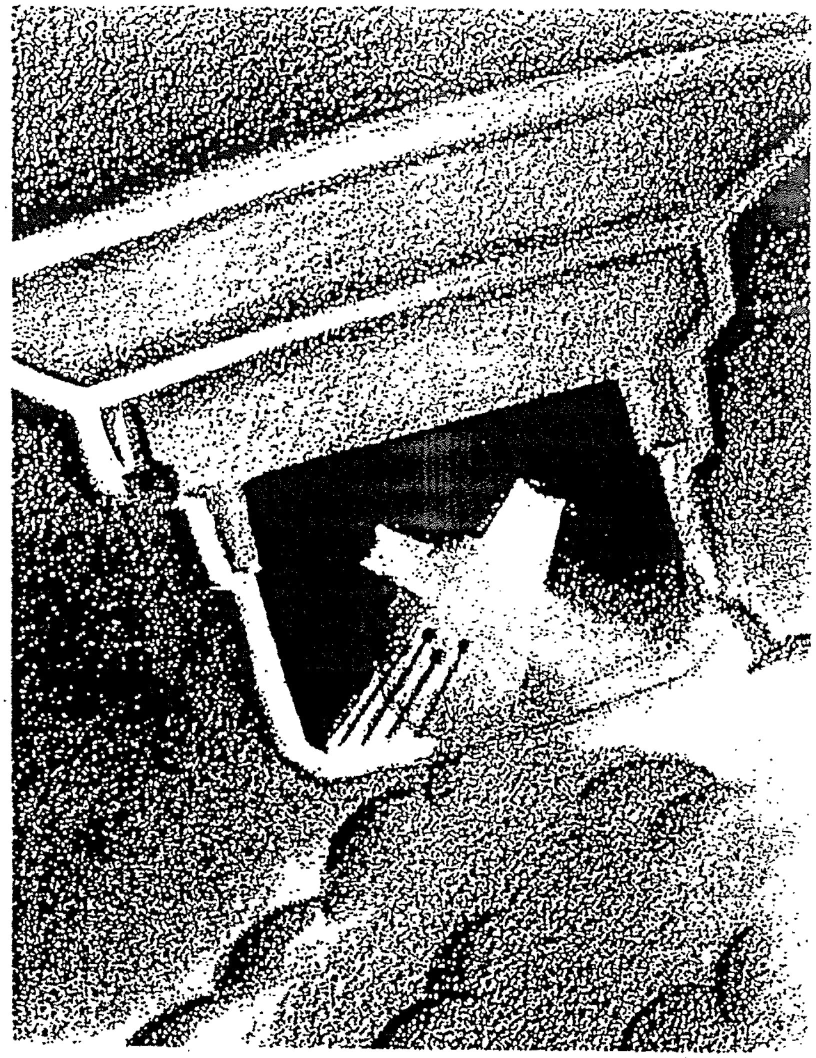

Current thinking on the performance of residential heat detectors compared to that of smoke detectors, as embodied in most U.S. codes, recently has been challenged.

This article assembles from the literature a comprehensive picture of what is known about the relative performance of these two detector types in residential fires. The studies cited here were identified in a recently published, comprehensive literature review[1] and are available in the open literature. In each case, the study has been summarized and its conclusions on heat and smoke detector performance are quoted.

Detector technology and standards during the 1960s

In the 1960s, the only fire detection devices available to homeowners specifically intended for use in the home were mechanically powered heat detectors, either the compressed-gas type or the spring-wound type.

These early devices, which originally were introduced to the market in 1955, had a UL space rating (an indicator of their sensitivity) of 25 feet, compared to the 70-foot rating of heat detectors being sold today. Using the relationship between the space rating and the time constant (τ) given in Table C-3.2.1.1 of the 1990 edition of NFPA 72E, *Automatic Fire Detectors*, this increase in space rating should equal an approximately fourfold increase in sensitivity.

The only smoke detectors then available were commercial-style photoelectric (scattering) types that were operated from a fire alarm control panel. These early photoelectric detectors demonstrated a slow response because their designs restricted smoke entry into the

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sensing chamber and because the typical 90° scattering angle was inefficient for the dark smoke particles that flaming combustion produced.

At that time, federal regulations required that installations of ionization-type detectors be individually licensed and that detectors be tested annually for leakage of the radioactive source material. After about 10 years of testing data indicated that no leakage ever occurred, these regulations were withdrawn in the late 1960s.

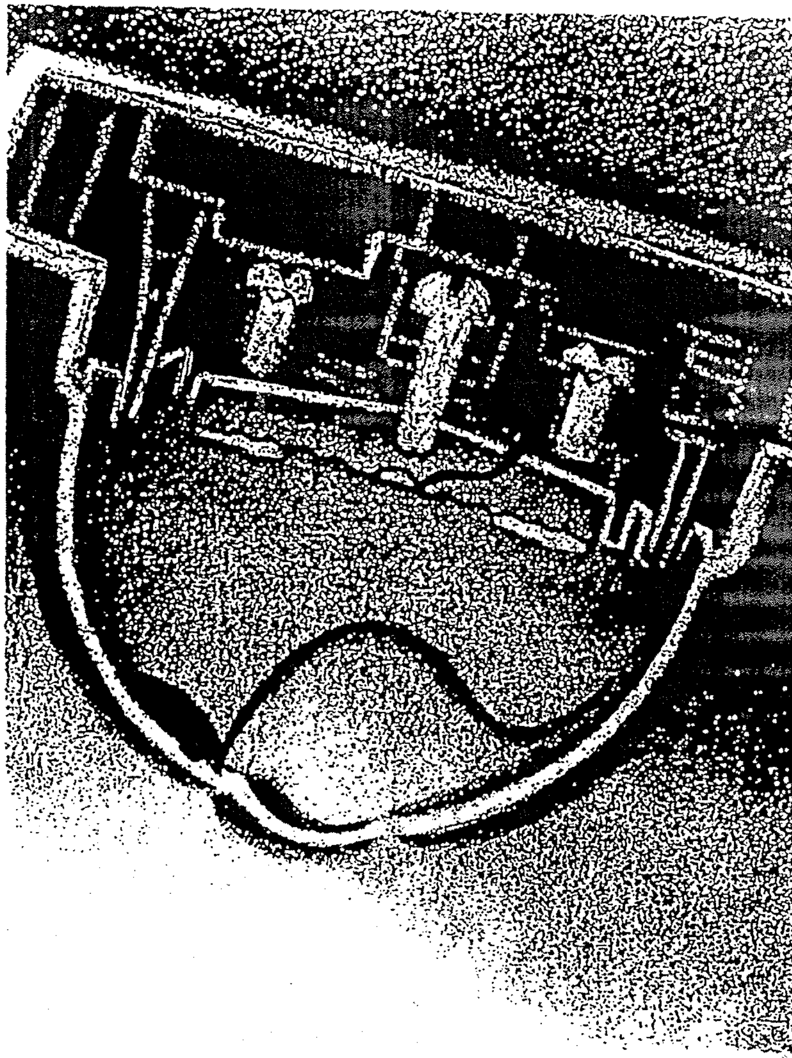
When the first edition of NFPA 74, *Household Fire Warning Equipment*, was published in 1967, the minimum requirement for a residential fire alarm system was a heat detector in every room and a smoke detector outside the bedrooms, all connected to a control panel. It is estimated that such systems were installed in fewer than 1 percent of U.S. homes because of the cost—about $1,500 for a small house.

Studies conducted during the 1960s

The earliest direct comparison of the performance of smoke and heat detectors in a residential setting was a study published by John McGuire and Brian Ruscoe of the National Research Council of Canada in 1962.[2] They examined reports of fatal fires in residential dwellings, classified as "unshared separate dwellings," that occurred between 1956 and 1960, resulting in 342 deaths.

Based on their judgment, (italics mine), they estimated the lifesaving potential if detectors had been installed in the dwellings in two configurations:

- a fixed-temperature heat detector activating at 150°F (66°C) in the area of fire origin—in effect, a heat detector in every



This review of the literature presents a comprehensive picture of the performance of residential detectors in fire tests.

DETECTORS

room, or

- two smoke detectors, one outside the sleeping room(s) or at the head of the main staircase in a two-story dwelling and one at the head of the basement stairs (if there was a basement).

The researchers concluded that the smoke detectors would have saved 41 percent of the 342 victims and that heat detectors would have saved 8 percent.

In 1960, the Los Angeles Fire Department conducted the first experiments on the performance of residential fire detection systems; the results were reported in the *NFPA Quarterly* in 1963.[3] The tests were designed to evaluate the detectors' ability to respond to two very different types of fires: smoldering fires initiated in an upholstered chair by dropped smoking materials, and fast, relatively smokeless fires in containers of trash.

The department conducted 13 tests in four different one- and two-story dwellings of ordinary construction. Tests 5 through 13 included photoelectric smoke detectors, and all the tests used spring-wound, residential heat detectors; these were the first independent tests of these devices reported in the literature. The results of the tests are summarized in Table 1.

The report concluded with a series of observations:

"In the slow, smoldering fires conducted during these tests:

"1. Disabling and near-lethal concentrations of carbon monoxide gas were recorded prior to the sounding of heat-activated fire alarms.

"2. Temperatures within the dwellings remained near ambient until such time as the upholstered furniture being burned burst into flames.

"3. Before operation of a heat-activated device, visibility within the dwelling was diminished to the point where, in bright, sunny, daylight conditions, people would be unable to rely on sight (as a means of receiving adequate warning) for evacuating the premises.

"4. In all tests in which smoke detectors were used, the smoke-activated device operated prior to the development of serious concentrations of carbon monoxide or smoke.

"In the rapid-burning rubbish fires conducted during these tests:

"1. Heat-activated devices operated soon after ignition of the fire and before serious carbon monoxide or smoke concentrations were in evidence.

"2. Smoke devices did not respond as long as the fire was free burning."

The next experimental study of detector performance reported was conducted by the Bloomington Fire Department in Minnesota in May 1969.[4] The tests took place in a 900-square-foot (84-square-meter) dwelling with two bedrooms and a bathroom on the first floor, an attic containing one bedroom, and an unfinished basement.

Smoke detectors were located in two first-floor halls outside the bedrooms and at the top of the attic stairway, and there was an additional smoke detector in the attic. Rate-of-rise heat detectors were placed in every room and adjacent to each smoke detector, and a single fixed-temperature heat detector was located in the attic bedroom. All the detectors were commercial types, connected to a fire alarm panel, rather than the single-station types common today.

Five tests were conducted "...to determine the reaction of various types of detectors to typical dwelling fires." The published report presented a summary of the results with a minimum of commentary and no statement of conclusions.

The first test involved a smoldering fire simulated by placing a roll of corrugated cardboard on a hotplate in the basement. Four detectors responded—three smoke detectors and one rate-of-rise heat detector—before conditions became untenable, although by the time the last three activated—two smoke detectors and the heat detector—conditions in the base-

One Is Not Enough

Richard W. Bukowski, P.E.

People are losing their lives in homes that contain *working* smoke detectors. We all have heard about fatal fires that occurred after the occupants had failed to replace a detector's battery or disabled a detector that sounded an alarm once too often because of smoke from cooking. But cases also have been reported where the detector was working and the fire department was at a loss to explain why the victims died.

While a few of these cases are a real mystery, many can be explained by the tests discussed in the accompanying article. For example, the Indiana Dunes tests showed that *having a smoke detetector on every floor level* provided 3 minutes' warning in 89 percent of the experiments. But they also showed that a single smoke detector outside bedrooms provided 3 minutes' warning in only 35 percent of the experiments. That is why NFPA 74 requires *smoke detectors on every level as a minimum.* (Italics mine.)

All too often, fatal fires that occur where working detectors are present begin on the first floor of a dwelling where the only detector is located outside second-floor bedrooms. In other fires, a closed door prevents smoke from reaching the detector. By the time the detector sounds an alarm, the escape path is blocked, the occupants perish unless they can escape through a window.

Survivors of some of these fires have said, "If only someone had told me I needed more than one detector, I certainly would have bought more." Sadly, some survivors have said that the fire department told them they needed "a smoke detector" to be safe, and they thought that meant only *one* detector.

A call to action

We must make sure the message we deliver to the public is the right one: *The absolute minimum number of smoke detectors needed in every home is one outside each separate sleeping area in the immediate vicinity of the bedrooms and one on each additional level of the family living unit, including the basements* (see paragraph 2-1.1.1 in the 1989 edition of NFPA 74). (Italics mine.) The more detectors there are, the safer the home will be.

Since smoke detectors are inexpensive, many people can afford to install one in every room. But smoke detectors should not be installed in kitchens, bathrooms, attics, or attached garages; detectors in these locations should be heat detectors.

People need to understand that a detector you cannot hear is worthless—and a detector that is more than one floor distant from the bedrooms cannot be heard in those bedrooms.

They also should be aware that a detector with a battery that is dead or missing, even for a few days, also is worthless. By replacing the batteries at least once a year, they'll always have an operating detector. The small investment of time and money spent replacing a battery can prevent a family tragedy.

ment were reported to be "quite noxious."

Test 2 involved an overheating electric motor in the kitchen. Five smoke detectors operated during the test, but no heat detectors activated. No comments were recorded on conditions in the home at the time the detectors activated.

Test 3 involved an overloaded electric cord under an upholstered chair in the living room. Four smoke detectors operated at times ranging from 1 minute 15 seconds to 12 minutes, and five heat detectors activated—four at 13 minutes and one at 15 minutes.

The report states that "Observers noted that when the first (smoke) detector operated, the living room was still tenable, but during the next 10 minutes (before the first temperature-sensitive detector operated), the smoke became unbearable."

Of special interest is the comment that "Besides the detectors shown in the diagrams, a spring-wound fixed-temperature device had been placed in the living room for test 3. That device operated 14 minutes after the arc." (The time that the cord began arcing was taken as the time of fire ignition.) Thus, the spring-wound heat detector located in the room of fire origin did not respond until several minutes after smoke conditions in the living room were considered "unbearable."

The fourth test involved a grease fire in the kitchen. The smoke detector in the front hall operated first. It was followed 1 minute later by the rate-of-rise heat detector adjacent to the stove in the kitchen, and then by the smoke detector in the rear hall 15 seconds later.

The final test involved a fire in a plastic wastebasket filled with trash in the kitchen, below the draperies. A smoke detector in the rear hall operated first, at 1 minute. It was followed by the smoke detector in the front hall at 3 minutes and by the rate-of-rise detector in the kitchen, the room of fire origin, at 3¼ minutes.

These tests were the first to demonstrate that smoke detectors *remotely located* from the room of origin consistently operated *before* heat detectors—in these tests, the more sensitive rate-of-rise type detectors—that were *in the room of fire origin*. (Italics mine.)

TABLE 1

Test Results

Test	Building	Test Fire	Smoke Detector Activation Time	Heat Detector Activation Time
1	3 room, 1 story	Chair	None present	119 min.
2	3 room, 1 story	Mattress	None present	Did not activate
3	3 room, 1 story	Chair	None present	84 min.
4	3 room, 1 story	Mattress	None present	95 min.
5	6 room, 1 story	Chair	38 min., 45 sec.	Did not activate
6	6 room, 1 story	Sofa	6 min., 40 sec.	64 min., 40 sec.
7	5 room, 1 story	Chair	25 min.	2 hours, 9 min.
8	5 room, 1 story	Fiber drum/trash	6 min.	5 min.
9	10 room, 2 story	Chair	21 min.	1 hour, 40 min.
10	10 room, 2 story	Chair	49 min.	Did not activate
11	10 room, 2 story	Box/trash	Did not activate	1 minute
12	10 room, 2 story	Box/trash	Did not activate	3 minutes
13	10 room, 2 story	Chair	1 hour, 40 min.	Did not activate

Detector technology and standards during the 1970s

By the start of the 1970s, the technology of residential fire detection was changing rapidly. About 1965, the single-station, ac-powered, photoelectric smoke detector was developed, but it was not effectively marketed until the appearance of battery-powered ionization-type devices in 1969 and 1970. Problems with the response of the early smoke detectors were being recognized and corrected. Mechanically powered heat detectors similarly were improved to increase their sensitivity and reaction time; spacing was increased to 30 feet, 50 feet, and eventually to 70 feet.

By the time the experiments discussed in this section were conducted, at mid-decade, the performance of the heat detectors and smoke detectors used in the tests was significantly improved over those used in prior tests and was essentially equal to that of current devices.

The 1974 edition of NFPA 74 was the first to recognize the potential benefits of having fewer than one device in every room. This standard contained a controversial system of "levels of protection."

In this system, the minimum level—level 4—required a single smoke detector outside bedrooms and one at the top of a basement stairway, following the earlier recommendations of McGuire and Ruscoe. The maximum level—level 1—required a traditional heat or smoke detector in every room and a smoke detector outside bedrooms. The controversy related to the fact that levels 2 through 4 were based solely on the judgment of the committee and no verifying tests were performed.

To resolve these concerns, the National Bureau of Standards (now the National Institute of Standards and Technology) contracted with the IIT Research Institute (IITRI) and Underwriters Laboratories to conduct a thorough study. This became known as the Indiana Dunes Study, which will be discussed in the next section.

Studies conducted during the 1970s

In 1974, the Japan Housing Corporation (JHC) sponsored a study of fire detector performance in residences.[6] Tests were carried out in two typical Japanese dwellings: a three-room, single-story structure with a 350-square-foot (32.4-square-meter) floor area, and a five-room, single-story house with a 485-square-foot (45-square-meter) floor area.

As in most Japanese houses, each room was closed off from the rest by doors because of the lack of central heating. The same situation is present in older houses in the United Kingdom, for the same reason. Fixed-temperature (140°F, 60°C), heat detectors, rate-of-rise thermal detectors, and smoke detectors were provided in every room.

Ten experiments were conducted and the following conclusions were made:

"1. The difference in operation times between a heat detector and a smoke detector is mainly dependent upon the time lag in smoke production and temperature-rise. For example, in...detecting a fire due to an oil stove, there is no time lag in operation time between a smoke detector and a rate-of-rise type/Class 2 spot detector, while a fixed-temperature type detector takes much time to respond.

"2. It is desirable to provide detectors [on] a room-to-room basis in [a] Japanese dwelling house, because the movement of [the] fire stream from the fire room to another [room] may be largely delayed due to many partitions such as sliding doors and transoms particular to the Japanese dwellings.

"3. From the viewpoint of safety for human life, smoke detectors are naturally desirable. However, [because of] the possibilities of false alarm, it is recommendable to avoid the use of smoke detectors [in] kitchens and bathrooms. Since there are many, but relatively narrow, rooms in a Japanese dwelling house and it is impracticable to provide every room with smoke detectors on account of economy, it is also recommendable to provide the rate-of-rise type/Class 2 spot detectors primarily and the fixed-temperature type/

special class [detector] with [a] nominal operation temperature of 60°C secondarily.

"4. Rooms in a JHC apartment house from which fire detectors are allowed to be omitted on account of construction cost are [the] toilet room and bathroom, where there are few sources of ignition. And if [it is] provided with [a] self-closing door, the vestibule is also included in the above-mentioned category."

At about the same time, IITRI and UL were beginning their tests in the United States in three houses scheduled for demolition as part of the expansion of the Indiana Dunes National Lakeshore Park.

In all, 76 experiments were performed in two phases of testing.[6,7] Both photoelectric- and ionization-type smoke detectors were installed in hallways—to correspond to the level 4 requirement of the 1974 edition of NFPA 74—and in the room of fire origin, so that a "smoke detector in every room" system could be evaluated. Since the Dunes tests are well-known and were heavily reported, I will not summarize them here.

Heat detector performance was judged by thermocouple readings taken at the smoke detector locations in the room of origin. In tests performed the first year, activation was presumed to occur when the thermocouple read 150°F (66°C), but both spring-wound and gas-powered 50-foot-rated devices were used in tests the second year in response to complaints from the heat detector industry.

Three of the reports' eight conclusions relate to the comparative performance of heat and smoke detectors:

"1. A residential smoke detector of either the ionization or photoelectric type with [a] small time lag would provide more than adequate lifesaving potential under most real residential fire conditions when properly installed....

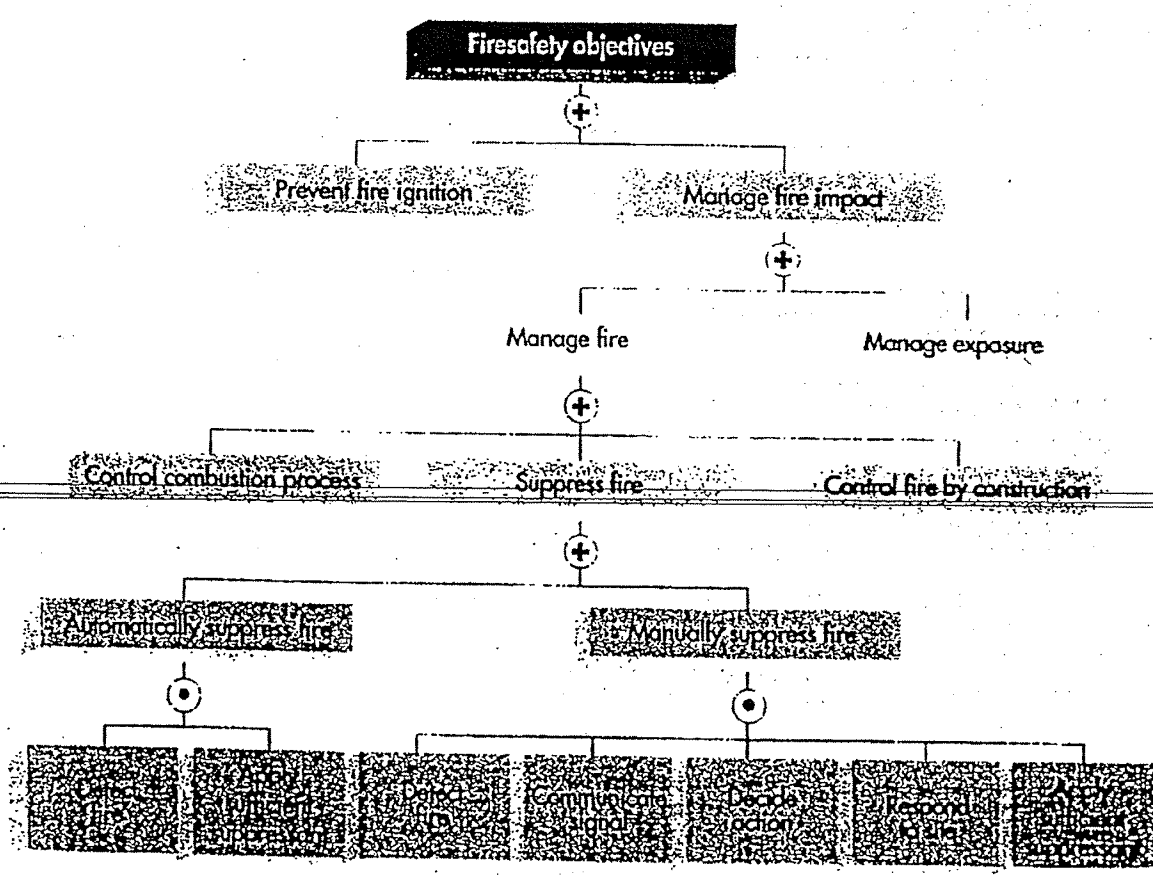
"3. Fixed-temperature (135°F, 57°C) or rate-of rise heat detectors in the room of fire origin provided little lifesaving potential. These detectors failed to respond to a majority of the fires, and when they did respond, they were considerably slower than smoke detectors located [at a] remote [distance] from the fire.

"5. Response time of detectors on the second floor for first-floor fires should be considered inadequate. Thus, it would appear that NFPA 74 should be revised to require at least one detector on each level of the residence."

After the results of the first year's tests were published, a Massachusetts advisory board performed an independent analysis of the data to support proposed state legislation requiring residential detectors.[8] In this analysis, a desired escape time of 3 minutes was assumed—between the time the detector alarmed and the time conditions were considered impassable anywhere along the primary egress route *within* the house. Escape through windows was not considered.

The performance of various detector arrangements was tabulated. The advi-

Excerpt From NFPA 550, Firesafety Concepts Tree



Automatic Sprinklers Are Needed, Too

Russell P. Fleming, P.E.

Automatic sprinklers are heat detectors and are recognized as alarm-initiating devices in numerous building and fire codes. But by no means should automatic sprinkler protection be equated to heat detection in terms of their overall impact on fire safety.

Like a heat detector, a sprinkler usually can be expected to respond at a later point of fire growth than a smoke detector. Once it has responded, however, an automatic sprinkler begins to fight the fire. Water from the sprinkler is expected to suppress or control the fire, reducing the rate of heat release and preventing the rapid development of untenable conditions.

In most studies comparing the relative effectiveness of smoke and heat detectors, success is measured by the ability of the detector to provide several minutes of warning before untenable conditions develop. While heat detection alone might fail in many of these instances, heat detection combined with automatic suppression generally would succeed, since the development of untenable conditions is precluded.

It is not surprising that in the past, some studies concluded that heat detectors alone might provide almost no escape time, especially in fast-developing fires. During the residential sprinkler development program in the late 1970s, it was found that sprinklers protecting typical residential furnishings often activated just as the heat-release rate of the fire was beginning a dramatic exponential increase.

In freeburn testing of the upholstered-furniture corner scenario, used as the basis for the residential sprinkler program, the convective heat-release rate of the fire was about 10,000 Btu (175 kW) per minute 2 minutes after ignition, but it increased to 200,000 Btu (3,500 kW) per minute within 1 additional minute.[1] This is basically the difference between the burning rate of a trash-basket fire capable of activating a fast response sprinkler and the burning rate of fully involved upholstered furniture capable of causing flashover in a small room.

The difference between detection alone versus combined automatic detection and suppression is clearly demonstrated in NFPA 550, *The Firesafety Concepts Tree*, in which the box labeled "detect fire" and the box labeled "apply sufficient suppressant" must connect through an "AND" gate to reach the box labeled "automatically suppress fire." Automatic sprinklers combine those two elements successfully and achieve automatic fire suppression. From that point, the route to the fire safety objective consists solely of "OR" gates. When you "automatically suppress fire," you proceed to "suppress fire," "manage fire," and "manage fire impact," and reach the "fire safety objective" at the top of the tree.

Without automatic suppression, the "detect fire" box must be linked through an "AND" gate with "communicate signal," "decide action," "respond to site," and "apply sufficient suppressant" in order to reach the "manually suppress fire" box. Each of these additional steps takes time, and during these crucial minutes the fire can easily grow to deadly proportions.

With a properly designed, installed, and maintained automatic sprinkler system, the fire is quickly controlled or suppressed, achieving the fire safety objective of protecting life and property.

1. B.G. Vincent, *Heat Release Properties for Three Selected Large-Scale Fuel Packages*, Factory Mutual Research Corporation, December 1985.

Russell P. Fleming is vice president of engineering at the National Fire Sprinkler Association.

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sory board found that a smoke detector on every level provided the desired 3 minutes of escape time in 89 percent of the experiments, compared to 11 percent for a heat detector in the fire room—in effect, a detector in every room.

The clear and decisive results of the Indiana Dunes tests and the analysis of the Massachusetts report resulted in changes to NFPA 74; the 1978 edition required smoke detectors on every level as the minimum requirement. Similar requirements subsequently were adopted in nearly every state and in many cities and counties in the United States, as well as in other countries.

After the first Dunes report was published, the experimental design and the test results were questioned in a *Fire Journal* article by E.L. Gallagher,[9] who represented the heat detector industry through a trade association, the Fire Equipment Manufacturers Association. A rebuttal by the National Bureau of Standards appeared in a subsequent issue of *Fire Journal*.[10]

In 1974, Factory Mutual Research Corporation performed another set of experiments that examined the performance of detectors in apartments.[11] The apartments were in high-rise buildings, although the height of the buildings had no impact on the results.

The test geometry consisted of a one-bedroom, 753-square-foot (70-square-meter) apartment that opened onto a 58-foot (17.7-meter) corridor. Ionization- and photoelectric-type smoke detectors and fixed-temperature (135°F, 57°C) and rate-of-rise heat detectors were used. The performance of the detectors was judged in 19 experiments on their ability to provide 2 minutes of warning before tenability criteria in the apartment were exceeded.

Pertinent conclusions reached in this study include the following:

"2. The ionization detector performed adequately in the protectable flaming fire starts and, in general, inadequately in the smoldering fire starts.[12]

"3. The photoelectric smoke detector did not perform adequately anywhere in the protectable flaming fire starts, but was adequate almost everywhere in the apartment in the smoldering fire starts of long duration.

"4. Both detector types performed adequately, by a wide margin, in the kitchen fires when located close to the fire. However, those detectors located at remote locations from the kitchen fires did not respond adequately.

"5. Neither of the heat detectors performed adequately, regardless of the fire and detector location."

In 1978, the Minneapolis Fire Department conducted a series of experiments to examine the performance of smoke and heat detectors in residences.[13] The test house was a four-bedroom, two-story dwelling with a basement. Smoke detectors and heat detectors (135°F, 57°C), were located on each floor level, near the central stairway. Eight tests were conducted with fires in various rooms on each floor.

The conclusions of the investigators included the following:

"Heat detectors alone should not be relied upon for early life safety warning in any area or room in the home.

"...both ionization and photoelectric types of smoke detectors gave good early warning of lethal conditions in the area of the detector, but are affected by barriers that prevent smoke travel (closed doors) and bad locations (dead-air spaces, etc.)."

In 1979, the Australian Department of Housing and Construction published a report on a series of four detector experiments conducted in a three-bedroom brick cottage.[14] Both ionization- and photoelectric-type smoke detectors and thermal (fixed-temperature, rate-of-rise) detectors were used.

Regarding the performance of the thermal detectors, the report stated that "Generally, the performance of thermal detectors in this type of fire environment showed them to be ineffective in providing time for occupants to move before escape paths become untenable. In the first three tests, the detectors either failed to operate or operated only after extinguishing procedures had commenced and the house was thoroughly smoke-logged."

On the performance of the smoke detectors, the report concluded that "The sensitivity of all the domestic smoke detectors tested was sufficient to trigger [an] alarm before escape paths became untenable."

A final study, equal in scope to the Dunes tests, was conducted by the Los Angeles Fire Department in 1978, but it was not published until 1983.[15]

This study, often referred to as the California Chiefs' Tests, has an interesting history. After the article by E.L. Gallagher was published, Gallagher decided to organize his own tests to prove his points of contention with the Dunes tests and, presumably, to demonstrate the value of heat detectors. He sought the assistance of the California Fire Chiefs' Association, which eventually conducted the tests, essentially following Gallagher's recommendations.

A three-bedroom, one-story test house and a two-bedroom, two-story test house were obtained in an area being razed for the extension of a runway at Los Angeles Airport. The houses were completely furnished, down to dishes in the kitchen and toothbrushes in the bathrooms.

In all, 71 experiments were conducted, from which the following conclusions on detector reliability were drawn:

"4. Smoke detectors (ionization or photoelectric) are more reliable than heat detectors as early warning devices for dwelling fires.

"5. Heat detectors alone may provide no escape time."

Summary

This article reviews 10 independent studies conducted in four countries over a 20-year period in which 206 experiments were reported. All the studies were conducted to evaluate the performance of residential heat and smoke detectors in providing life safety for the occupants in residential fires.

All 206 experiments were real-scale tests in houses or apartments, and most of them used actual items—upholstered furniture, mattresses, wiring, motors, trash, etc.—as the fire source. All the tests used standard heat and smoke detectors installed in typical locations in the test houses. All the detectors were available for purchase at the time the tests were conducted, and all were calibrated to alarm at levels of heat and smoke consistent with devices available in stores.

All the studies presented conclusions that were essentially identical:

• When either ionization or photoelectric smoke detectors are located outside the bedrooms and on each level of a house, they provide adequate warning to allow the occupants to evacuate through their normal egress routes in most residential fire scenarios; and

• Even when heat detectors are located in the room of fire origin—in effect, requiring a heat detector in every room—they do not provide adequate warning in most fire scenarios.

In every case where the reports elaborate on where a heat detector might be used, they state that heat detectors should be used only in kitchens or other areas where smoke detectors cannot be used, such as garages and attics. These comments are identical to the current requirements in NFPA 74 regarding heat detectors.

An international literature search for publications dealing with the subject of fire detection systems was recently completed.[16] This review identified 975 citations, 100 of them in foreign languages, that were published in the past 15 years. As of June 1991, the cut-off date for inclusion in the bibliography, no studies other than those cited here—and one in which only smoke detectors were tested[17]—were published in the open international literature that dealt with this topic.

Editor's note: The conclusions presented in this article regarding "heat-activated devices" were based on the tests of detectors, not sprinklers.

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1. R.W. Bukowski and N.H. Jason, *International Fire Detection Literature Review and Technical Analysis*, National Fire Protection Research Foundation, Quincy, Mass., 1991.

2. J.H. McGuire and B.E. Ruscoe, *The Value of a Fire Detector in the Home*, Fire Study No. 9, National Research Council of Canada, Division of Building Research, Ottawa, Ont., Canada, December 1962.

3. "Fire Detection Systems in Dwellings—Los Angeles Fire Department Tests," *NFPA Quarterly*, Vol. 56, No. 3 (January 1963), pp. 201-215.

4. "Home Fire Alarm Tests," *Fire Journal*, Vol. 65, No. 4 (July 1971), pp. 10-15.

5. Y. Eguchi, "Automatic Fire Detection in Japanese Dwellings," Association of Fire Alarms of Japan, U.S./Japan Cooperative Program on Natural Resources, Panel on Fire Research and Safety, October 19-22, 1976, Tokyo, Japan, *Fire Detection*, Vol. 6, pp. 1-16.

6. R.W. Bukowski, T.E. Waterman, and W.J. Christian, *Detector Sensitivity and Siting Requirements for Dwellings*, NBSGCR 75-51, National Bureau of Standards, 1975, 343 pp. Available from National Technical Information Services; order no. PB247483.

7. S.W. Harpe, T.E. Waterman, and W.J. Christian, *Detector Sensitivity and Siting Requirements for Dwellings—Phase 2*, NBSGCR 77-82, National Bureau of Standards, 1977, 379 pp. Available from National Technical Information Services; order no. PB263882.

8. Rexford Wilson, *Computer Analysis of Data on Fire Detectors Available for Purchase in Massachusetts*, Massachusetts Fire Prevention, Fire Protection Board, Commonwealth of Massachusetts, Boston, Mass., 1976.

9. E.L. Gallagher, "FEMA: NBS Tests Do Not Reflect Reality, *Fire Journal*, Vol. 71, No. 2 (March 1977), pp. 19, 38-41.

10. R.G. Bright, "NBS Answers FEMA's Criticisms of the Indiana Dunes Tests of Residential Smoke Detectors," *Fire Journal*, Vol. 71, No. 5 (September 1977), pp. 47-49, 99.

11. G. Heskestad, *Escape Potentials From Apartments Protected by Fire Detectors in High-Rise Buildings*, FMRC Report RC74-T-15, Factory Mutual Research Corp., Norwood, Mass., 1974.

12. In this report, the author refers to protectable and unprotectable fires. Where the combination of detector location, fire location, and fire growth rate resulted in the single means of egress from the apartment being blocked prior to the time that the first heat or smoke combustion products reached the closest detector location, the test was classified as unprotectable.

13. D. Ozment, *1976 Bicentennial Home Smoke Detector Test*, Minneapolis Fire Department Bureau of Fire Prevention, Minneapolis, Minn., 1976.

14. P. Johnson and A.W. Moulen, *Fire Detection in Typical Cottage*, Technical Record 453, Department of Housing and Construction, Chatswood, N.S.W., Australia, November 1979.

15. *The California Fire Chiefs' Association Residential Fire Detector Test Program*, Los Angeles Fire Department with assistance from California State University at Los Angeles, under contract to the International Association of Fire Chiefs' Foundation, 1983.

16. Bukowski and Jason, *International Fire Detection Literature Review and Technical Analysis*.

17. P.F. Johnson and S.K. Brown, "Smoke Detection of Smoldering Fires in a Typical Melbourne Dwelling," *Fire Technology*, Vol. 22, No. 4, 1986, pp. 295-340.

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Keeping the Smoke Detectors Operational: The Dallas Experience

William Jernigan, Ph.D.

As has been verified repeatedly by national and local fire experience, effective use of smoke detectors reduces loss of life and property. Conversely, ineffective use or the absence of smoke detectors jeopardizes lives in a fire. These facts have been further validated by a four-year fire prevention education and smoke detector distribution project conducted by the Dallas, Texas, Fire Department from 1983 to 1986.

With funding from the City of Dallas' Community Development Block Grant provided by the United States Department of Housing and Urban Development, the fire department supplied and/or installed battery-powered ionization smoke detectors at no cost to the occupants of 12,743 residences in 14 census tracts in which there was a high incidence of fire. This project concentrated selected fire prevention resources in specific neighborhoods for maximum possible contact with the residents (see Table 1).

During the first year of the project, the fire department chose to concentrate on four census tracts that contained approximately 4,400 owner-occupied and tenanted residences in three different sectors of the city. The department selected these particular tracts because the incidence of fire in them during Fiscal Year 1980–1981 was significantly greater than the citywide average: The combined rate in these four tracts was 1.18 fires per 100 homes, compared with 0.60 fires per 100 homes throughout Dallas.

Dr. William Jernigan is a public administrator with the Dallas, Texas, Fire Department.

Dallas resident Martha Sims (center) receives a smoke detector from Dallas Fire Department representatives Kim Gawlik (left) and E. J. Davis (right).

The grant criteria also ensured that the residents of these tracts would be highly unlikely to have existing smoke detector protection. They belonged to low- and moderate-income or single-member households; were renters, inner city residents, or elderly; or belonged to racial minorities. National surveys in the late 1970s revealed that less than half such households had a workable smoke detector on the premises.

In the three succeeding fiscal years, census tracts with comparable residential fire experience were selected for the fire prevention and smoke detector contacts. The 1983–1984 project covered three tracts with an estimated 5,400 eligible residences; 1984–1985 covered five tracts with an estimated 4,500 residences; and 1985–1986 covered two tracts with an estimated 500 residences. During this period, owner-occupied dwellings received priority because all rental housing in Texas was required by statute to be equipped with a smoke detector provided by the landlord as of September 1, 1984.[1]

The continuing fire problem in census tracts meeting the grant's household income criteria was evident in the annual reports of fire incidence. From 1982–1983 through 1985–1986, 70.6 percent of those tracts eligible for the grant had a fire rate that exceeded the citywide rate. In fact, 77 of the 109 eligible tracts had rates greater than the 0.558 fires per 100 homes experienced throughout the city.

In each of these four fiscal years, the fire department tried to reach as many residents as possible in the targeted neighborhoods. An initial mailing in both English and Spanish described the need for smoke detector protection, encouraged firesafety awareness, and announced a forthcoming visit by a fire department representative. Then a uniformed fire prevention officer went to

[1] The statute was silent on the maintenance of smoke detectors. Neither the landlord nor the tenant was specified as obligated to replace a depleted battery, and the landlord is exempted by the statute from such an obligation during the term of the tenant's occupancy. (*Vernon's Texas Codes Annotated*, "Property Code," Sections 92.251 through 92.262.)

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each home in the area to offer to provide and install a detector.

While at each residence, the representative took note of the firesafety measures the residents were already practicing and recommended needed changes. Representatives also gave each resident a pamphlet published by the fire department that stressed the importance of installing and maintaining smoke detectors and that recommended other residential fire prevention precautions.

Using these procedures, the fire department supplied a smoke detector to 85 percent of the qualifying residences in 14 census tracts during the four years the project was conducted. Some homes were given two detectors to ensure coverage of all sleeping rooms. In all, 14,290 smoke detectors were provided and/or installed.

Table 1
Summary of Neighborhoods Receiving Fire Prevention Emphasis

Census Tract	Statistical Community	Fiscal Year of Contacts	No. of Detectors Provided	% of Qualifying Residences Receiving Detector[1]
20	Kessler-Stevens	85–86	338	83.6
27.01	Fair Park	83–84	1,010	86.1
34	South Dallas	84–85	174	69.6
36	South Dallas	82–83	430	93.4
37	South Dallas	84–85	1,389	72.0
40	South Dallas	84–85	609	69.7
41	Trinity	84–85	584	[illegible]
47	Jefferson	85–86	254	83.8
55	Trinity	82–83	[illegible]	[illegible]
56	Lisbon	83–84	[illegible]	[illegible]
57	Lisbon	84–85	[illegible]	[illegible]
101	West Dallas	83–84	[illegible]	[illegible]
105	West Dallas	82–83	[illegible]	[illegible]
106	West Dallas	82–83	[illegible]	[illegible]
Total			14,290	

[1] The number of qualifying residences was derived from the 1980 United States Census total of owner-occupied and rental residences [illegible]

Table 2
Survey Data Summary

2,528 residences surveyed, all of which had received a project detector
1,678 residences with detector installed (66.4 percent)
1,408 residences with installed detector operable (83.9 percent)
270 residences with installed detector inoperable (16.1 percent)
850 residences with detector missing (33.6 percent)

Analysis of the Project

In its 1986 project, the fire department mailed a bilingual detector maintenance reminder to each of the 12,743 homes that had received a detector in previous years, then randomly surveyed approximately 20 percent, or 2,528, of those homes.

According to the survey, 66.3 percent of those 2,528 residences had an operable smoke detector that had been provided either by the fire department or another source, such as the resident or the landlord. The survey also found that 55.7 percent, or 1,408, of the residences had an operable detector from the fire department, while 17.6 percent, or 445, of the dwellings had a detector from another source. Another 4.7 percent, or 119, of the homes surveyed had received operable detectors from both the fire department and another source.

In 270 of the residences surveyed, the installed detector was inoperable, and detectors were actually missing from 850 of the dwellings (see Table 2). Presumably, occupants of 75.9 percent of the homes had deliberately removed the entire detector unit, while the remainder had removed the battery, often before it became depleted.

Random interviews provided varying explanations for the removal or lack of maintenance of the detectors. Some people considered them a nuisance because they occasionally reacted to nonhostile combustion, such as smoke from frying, grilling, cigarettes, or cigars. Others described the low-battery indicator — an intermittent chirping of the alarm horn — as an annoyance. They removed the expiring battery but failed to install a fresh one.

This detector usage pattern was consistent with a national survey of residential protection performed the year before the Dallas project began. The study, sponsored by the Federal Emergency Management Agency (FEMA), estimated that two-thirds of residences nationwide had smoke detector protection.[2]

Acquiring a smoke detector is an essential solution to reducing the vulnerability of residents of inner city neighborhoods to fire. However, it is not a permanent solution. Once a detector has been installed, it must be properly maintained if it is to continue operating, and such maintenance is the resident's responsibility.[3]

Among residents receiving smoke detectors through the Dallas project, motivation to maintain the unit varied

[2] *Residential Smoke and Fire Detector Coverage in the United States: Findings from a 1982 Survey*, Federal Emergency Management Agency, Washington, DC, 1982, p. II-2.
[3] The need for engendering motivation to maintain smoke detectors as life-saving devices has been well documented in national publications. See, for example, Joan L. Gancarski and Tom Timoney, "Home Smoke Detector Effectiveness," *Fire Technology*, Vol. 20 (November 1984), pp. 57–64.

Table 3
Residences With Operable Smoke Detector by Ownership as of 1986 Survey Date

Year Received Detector	1983		1984		1985	
Occupied by	Owner	Tenant	Owner	Tenant	Owner	Tenant
Percent of residences with operable Community Development detectors of total residences surveyed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Percent of residences with operable other detectors of total residences surveyed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4
Single-Family Fire Trend in 12 Census Tracts

	Fiscal Year 1983–1984	Fiscal Year 1984–1985	Fiscal Year 1985–1986
Number of fires single-family housing	[illegible]	[illegible]	[illegible]
Property loss single-family fires	[illegible]	[illegible]	[illegible]
Average loss per fire	[illegible]	[illegible]	[illegible]
Loss in tracts as percentage of citywide single-family fire loss	[illegible]	[illegible]	[illegible]

and was informally correlated with the ownership status of the resident. Homeowners were found to have an operable detector at a rate of 63.9 percent, while tenants maintained their detectors at a rate of 40.0 percent. The pattern of greater attention to detector maintenance by owners is evident in Table 3. An examination of the percentages of operable smoke detectors over time indicates the residents' failure to maintain the units.

There appeared to be no significant pattern in the maintenance of the detectors provided by the project based on ownership status. In comparing the three-year-old installations with the two-year-old, for example, the operability percentage increased at a greater rate for tenant-occupied residences than they did for owner-occupied dwellings. However, the reverse occurred between the two-year-old and one-year-old units.

Among detectors acquired from a source other than the fire department, ownership status did not indicate any motivation to keep them in operating condition, either.

The low percentage of rental residences with an operable detector may suggest that the 1984 Texas statute on detector installation was not being observed. If detectors had been installed by landlords pursant to the statute, there would presumably be a higher rate of operable detectors in rental residences. But only 15.5 percent of such homes had an operable detector from a source other than the Dallas Fire Department.

Typically, landlords would expect a tenant to replace depleted batteries. However, motivation to do so was found to be low among tenants. Futher indicative of the lack of tenant motivation to acquire smoke detector protection is the fact that only 2.0 percent of the rental residences surveyed had operable detectors provided by both the fire department and another source. Just 17 renters maintained the fire department detector and acquired a detector from another source.

One of the project's achievements was an increase in residents' awareness of fire prevention and smoke detector protection. An estimated 5,800 residences could be assumed in the summer of 1986 to have an operable detector as a result of this project. This estimate is based on the survey finding that only 15 percent of the residences participating in the project had an operable detector from a source other than the fire department. Indeed, the vast majority of residences did not have a smoke detector when the fire department originally contacted the occupants. Presumably, residents lacked the knowledge and motivation to acquire their own detectors.

Fire Experience in Project Neighborhoods

The impact of the Dallas Fire Department's project can be assessed from fire experience data and individual fires.

Assuming that an operable smoke detector allows more timely control of a fire, benefit may be inferred through reduced property loss, and data collected for single-family residences do indicate a favorable pattern in the reduction of property loss. According to Table 4, there was a drop in total property loss in single-family residences, in loss per fire, and in the percentage of the city's total single-family residential loss for fires in the 12 selected census tracts from Fiscal Year 1983–1984 through Fiscal Year 1985–1986.

Other specific patterns were also noteworthy. In the spring of 1983, the Dallas Fire Department contacted an estimated 93.4 percent of the residents in Census Tract 36 and provided them with detectors. During Fiscal Year 1982–1983, seven fires with an average loss of $7,260 had occurred in single-family residences. During the following fiscal year, the same number of fires occurred, but the loss per fire declined by 8.6 percent to $6,637.

More significant decreases occurred in the two subsequent fiscal years. From

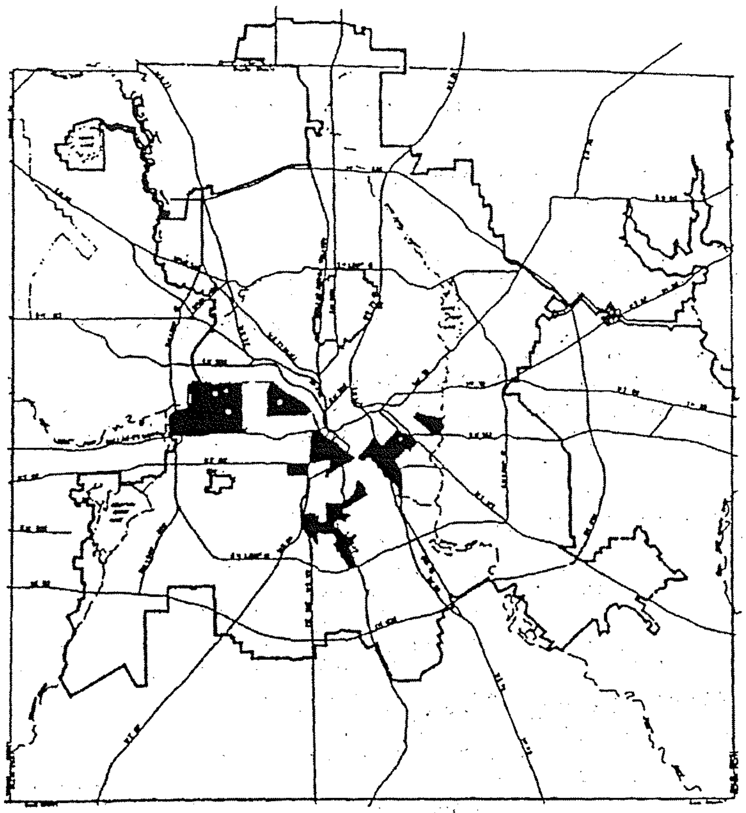
1983–1984 to 1984–1985, the number of single-family residential fires decreased from seven to three and the loss per fire dropped to $2,008. And in 1985–1986, only one single-family residential fire occurred, with a loss of $4,000.

In Census Tract 57, smoke detectors were provided to residents in the summer of 1985. In the following year, single-family fires declined by 53.1 percent, from 32 to 15, and the property loss by 62.1 percent, from $226,000 to $85,900. Among the 14 tracts in which detectors were provided, Census Tract 57 was unusual in that both one-time central distribution and door-to-door contacts were used. On June 15, 1985, persons from 316 dwellings came to a publicized location to receive a smoke detector. The fire department then contacted the other residents of the tract to achieve an estimated 69.8 percent distribution in the neighborhood.

Fire experience data for a group of census tracts also indicate positive trends. For example, detectors were installed in three census tracts in the spring of 1984. During that year, 84 residential fires occurred in those neighborhoods. In the following year, 76 fires occurred. This decrease was attributed to fewer multifamily housing fires.

Interviews with those affected by fire were also used to evaluate residential fire experience in the project neighborhoods. As fires occurred between 1983 and 1986, project personnel obtained information from the victims and from the formal fire department investigation reports. Respondents to the 1986 survey were also asked whether they had experienced fires in their homes after receiving their fire department smoke detectors and whether they were aware of any fires in their neighborhoods.

Typical of the incidents in which smoke detectors distributed by the fire department provided early warning was a fire in an old two-story, single-family home on May 16, 1984. Two adults and nine children were asleep on the second floor of the house that morning. Another adult, a woman, had risen at about 6:00 am, but had subsequently returned to bed. At 6:22, however, she was alerted to a fire in an unoccupied room on the first floor by the first-floor smoke detector. The woman and another adult alerted the remaining occupants, all of whom escaped through the rear of the house.



These are the areas in which the Dallas Fire Department conducted its smoke detector distribution program.

In an interview conducted after the fire, the adults said that by the time they were awakened by the alarm, the fire was extensive and that without the smoke detector warning, the children asleep on the second floor might not have escaped safely. The cause of the fire was an overloaded electrical extension cord, and the loss was estimated at $7,000.

Another such incident occurred in an old single-family house at 12:03 on the afternoon of June 17, 1984, when an elderly man left food cooking unattended on the kitchen stove while he went into another room. He was alerted to the fire by the smoke detector and returned to the kitchen to discover that flames had already spread into an adjoining room. He rushed to a front room to find his wheelchair-bound wife and was able to move her to safety. Property damage in this case was estimated to be $22,000.

On November 21, 1985, still another family escaped death and injury thanks to its smoke detector when a fire of electrical origin spread from the bathroom throughout their old single-family residence. The smoke detector sounded around 11:47 pm, and all the sleeping occupants except two pet dogs escaped safely as the house became fully charged with smoke. The estimated loss was $2,000.

Even if residents did not receive a smoke detector from the fire department, the department's project often had an impact on their awareness of fire prevention precautions.

For example, the fire department was unable to provide the resident of one

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One-Third of Home Detectors Don't Work

A new special study recently released by the NFPA Fire Analysis Division estimates that one-third of home smoke detectors in the United States are no longer operational. A definite trend toward growing problems with non-operational detectors could leave half the homes with detectors unprotected in less than a decade.

The study, "When Detectors Don't Operate — A Growing Problem," combines new analysis assumptions and calibration with local special studies to reanalyze the national fire incident data on detector performance. The report also includes information on detector use and performance outside the home.

The study is available to NFPA members for $15.00, to nonmembers for $16.50, and to the fire service for $9.00 from the NFPA Fire Analysis Division, Batterymarch Park, Quincy, Massachusetts 02269. Information on many other special studies and data analysis services offered by the Division is available upon request.

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small single-family house with a detector, although they tried to reach her four times. Nonetheless, her house was equipped with a privately acquired detector by March 2, 1983, when a fire occurred in the attic. The resident had bought the detector at the urging of her mother, who lived elsewhere in the neighborhood and had received one from the fire department. Thus, when fire broke out in the attic, the smoke detector alerted the sleeping occupants before smoke was even visible in the living area. The estimated loss came to $2,500.

Unfortunately, evidence demonstrates that residents were not always motivated to apply firesafety procedures and maintain the detectors supplied by the fire department project. This was the case in seven fires that resulted in 13 fatalities and at least two serious injuries. Conceivably, some, if not all, of these casualties could have been avoided if the smoke detectors had been maintained.

The residential fire resulting in the highest loss of life in Dallas history occurred in a single-family home which had received a fire department smoke detector 18 months earlier. At 1:47 on the morning of January 9, 1986, four adults and three children were killed and two other adults and an infant were injured in a fire that started when an electric space heater ignited a living room sofa. The metal mounting bracket of the detector was found on the hallway wall near the bedrooms in which the fatalities occurred, but the detector itself was missing. Later interviews revealed that the occupants had not replaced the original battery when it expired and had thrown the detector away.

At 4:26 pm on November 29, 1984, another fire in a single-family dwelling resulted in the death of a 4-year-old boy. The fire department had installed a detector in the house nine months earlier, but the residents had removed it when the low-battery indicator began sounding. The metal mounting bracket was found near the bedroom where the child died. The other occupants of the house, three adults and another child, managed to escape the blaze, which started in the kitchen.

Similar circumstances existed in other single-fatality fires in homes that were supplied with detectors in the spring of 1983 and 1984. Fire department investigators found no operable smoke detector in any of these fatal fires.

Among the victims of five single-fatality fires that occurred in 1984 and 1985 were several elderly persons. In July and December 1984, a 74-year-old woman and an 87-year-old woman died in fires in their homes. And in January, March, and July 1985, residential fires killed a 76-year-old woman, a 73-year-old man, and a 94-year-old man. These deaths confirm the FEMA report's findings that the elderly are particularly vulnerable to fire.[4]

In Conclusion

All in all, the results of the Dallas Fire Department project were positive. In scores of incidents, early warning of fire enabled occupants to discover the fire quickly, escape without death or injury, report the fire, and minimize property loss.

In addition, owners' and tenants' motivation to maintain smoke detectors was marginally higher after the project than it was presumed to be before the project. The follow-up survey conducted in 1986 found that smoke detectors provided by the fire department were operable in 64 percent of the owner-occupied homes and in 40 percent of the tenant-occupied homes.

Unfortunately, lives and property were also lost during the period in which the project was conducted. Thirteen people perished in dwellings that had received detectors and fire prevention information from the fire department. In each case, the detector had been removed or deactivated before the tragedy. Thus, ineffective use or the absence of a detector defeated its life-saving purpose.

In fact, there is no known instance in which a properly installed and maintained smoke detector supplied by the Dallas Fire Department during the project failed to react to the ignition of a fire that caused death or injury. Nevertheless, interviews suggest that, in an estimated 75 percent of the homes without an operable detector, the resident intentionally removed and disposed of it.

An estimated 5,800 Dallas homes could be assumed, based on survey data, to be protected by operational smoke detectors at the time of the survey. Conceivably, these residences would be unprotected if the project had not been undertaken.

Smoke detectors are a simple and reliable means of preventing many of the tragedies caused by fire. The challenge to the fire service and to firesafety educators everywhere is motivating the public to obtain, retain, and maintain smoke detectors as essential life-saving devices. △

[4] *Residential Smoke and Fire Detector Coverage in the United States: Findings from a 1982 Survey*, p. II-2.

Special Article

SURVEILLANCE AND PREVENTION OF RESIDENTIAL-FIRE INJURIES

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ABSTRACT

Background The majority of severe and fatal burn injuries result from residential fires. We studied the effectiveness of a smoke-alarm–giveaway program in the prevention of burn injuries in an area with a high rate of such injuries.

Methods We collected data on burn injuries in Oklahoma City from September 1987 through April 1990. The target area for the intervention was an area of 24 square miles (62 km²) with the highest rate of injuries related to residential fires in the city. We distributed smoke alarms door to door in the target area and then surveyed alarm use and function in a sample of the homes that had received an alarm. We also calculated the rates of fire injury per 100,000 population and per 100 fires for both the target area and the rest of the city before and after the smoke-alarm giveaway.

Results Before the intervention the rate of burn injuries per 100,000 population was 4.2 times higher in the target area than in the rest of Oklahoma City. An initial survey indicated that 11,881 of the 34,945 homes in the target area (34 percent) did not have smoke alarms. A total of 10,100 smoke alarms were distributed to 9291 homes; 45 percent were functioning four years later. The annualized fire-injury rates declined by 80 percent in the target area during the four years after the intervention (from 15.3 to 3.1 per 100,000 population), as compared with a small increase in the rest of the city (from 3.6 to 3.9 per 100,000 population). There was also a 74 percent decline in the target area in the injury rate per 100 fires (from 5.0 to 1.3; rate ratio, 0.3; 95 percent confidence interval, 0.1 to 0.6), as compared with a small increase in the rest of the city.

Conclusions A targeted intervention involving a smoke-alarm–giveaway program can reduce the incidence of injuries from residential fires. (N Engl J Med 1996;335:27-31.)

BURNS are the fourth leading cause of death from unintentional injury in the United States and result in 1.4 million injuries each year.[1,2] Residential fires cause over 75 percent of all deaths from fires and burns.[3-6] The southern part of the United States, including Oklahoma, has the highest regional rate of death from fires (2.5 deaths per 100,000 population)[3,4,7]; this high rate may be due to rural poverty, a lower prevalence of smoke alarms, and greater use of portable heating equipment.[2,8,9] Although the absence of functional smoke alarms in residential dwellings is a risk factor for subsequent injury or death,[6,10,11] surveillance data have not been used to evaluate whether a program to increase the prevalence of smoke alarms in high-risk populations would reduce fire-related morbidity and mortality.

The Oklahoma State Department of Health made burn injuries resulting in hospitalization or death a reportable condition and began active surveillance in September 1987. The purpose of the surveillance system was to guide the development and evaluation of prevention efforts by defining groups at potentially high risk for burn injuries and the circumstances resulting in such injury. The surveillance data identified a target area in south central Oklahoma City with a high rate of injuries related to residential fires. This study describes the use of surveillance, first to identify the need for a community-based intervention (a large-scale smoke-alarm–giveaway program) and then to measure the efficacy of the intervention in reducing residential-fire–related morbidity and mortality in a high-risk population.

METHODS

Surveillance

Surveillance of fire-related injuries resulting in hospitalization in the Oklahoma City Standard Metropolitan Statistical Area

From the Injury Prevention Service (S.M., M.R.-D.) and the Epidemiology Service (G.R.I.), Oklahoma State Department of Health, Oklahoma City; the National Center for Injury Prevention and Control, Centers for Disease Control and Prevention, Atlanta (M.R.); and the Office of the Chief Medical Examiner (F.J.), Baptist Medical Center of Oklahoma (P.S.), and Children's Hospital of Oklahoma (W.T.) — all in Oklahoma City. Address reprint requests to Ms. Mallonee at the Injury Prevention Service-0307, Oklahoma State Department of Health, 1000 NE 10th, Oklahoma City, OK 73117-1299.

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(all hospitals included) was conducted from September 1, 1987, through April 30, 1994. A case was defined as a burn or smoke-inhalation injury (*International Classification of Diseases, 9th Revision, Clinical Modification*, codes 940.0 to 949.9 or 987.9) in any person who died or was hospitalized. Fatal injuries were identified weekly from records of the Office of the Chief Medical Examiner. A case of residential-fire-related injury was defined as a burn or smoke-inhalation injury caused by a fire in an occupied dwelling resulting in the hospitalization or death of a resident; no other causes of injury (e.g., blunt trauma or falls) were included. For each case a standard form was completed with the use of a combination of medical-record review, interviews with patients and their families, and interviews with fire-department employees; the epidemiologic data collected comprised demographic and medical information, including contributing factors (i.e., alcohol use and physical or mental impairment), and the smoke-alarm status of the residence. Completeness of the reporting of cases was validated by comparison of data from hospital discharge records, the fire department, the medical examiner, vital-statistics files, and newspaper clippings.

The rates of residential-fire-related injuries were calculated per 100,000 population (the number of cases as described above ÷ the 1990 U.S. Census population × 100,000) and per 100 fires (the number of cases ÷ the number of fires in occupied dwellings according to the Oklahoma City Fire Department × 100). This led to the identification of the area of Oklahoma City with the highest rate of fire-related injuries and death. Although the true prevalence of smoke alarms in the target area was unknown, data from the Oklahoma City Fire Department suggested that it was considerably lower in the target area than in the other residential areas of Oklahoma City.

Implementation of the Program

According to the 1990 U.S. Census, Oklahoma City covered 621 square miles (1608 km²) and had a total of 444,719 persons residing in 213,607 dwellings. The target area was a 24-square-mile (62-km²) section near the middle of the city, where 16 percent (73,301 persons) of the total population resided in 16 percent (34,945) of the dwellings (single- or multiple-family dwellings, excluding apartments). The surveillance data indicated that 47 percent of the injuries resulted from fires started by young children playing with fire ("fire play"), 17 percent from fires started by cigarettes or smoking, 13 percent from fires caused by flammable liquids, 10 percent from fires caused by a heating device, and 13 percent from fires with other or unknown causes. This distribution varied considerably from that in the rest of the city, where injuries most often resulted from fires associated with heating devices (42 percent), followed by cooking (14 percent), cigarettes or smoking (11 percent), fire play (8 percent), electricity and flammable liquids (6 percent each), and other or unknown causes (14 percent).

To determine how many smoke alarms were needed in the target area, we estimated the prevalence of smoke alarms using information obtained by uniformed firefighters during on-site interviews of a random sample of 5 percent of the homes (n = 1615). At each home the firefighters requested information on the presence and functional status of a smoke alarm and confirmed the status of the alarm by inspecting it. To estimate the number of homes without a smoke alarm, we applied the prevalence rates found in the survey to the 34,945 occupied homes in the area. We estimated the proportion of homes with no alarm that were reached by the intervention by comparing the number of homes that received an alarm during the project with the estimated number of homes with no alarm.

Homes in the target area (comprising four ZIP Codes) that did not have any functioning smoke alarm were eligible for the intervention. The intervention involved a coalition of community agencies and volunteers who distributed alarms door to door in the target area between May and November 1990. Any resident who requested an alarm could have one installed. All the residents who received an alarm also received educational materials regarding the installation and maintenance of the smoke alarms, prevention of the leading causes of fires, and escape from fires. They also signed a statement agreeing to allow program representatives to inspect the alarm at a later date.

Program Evaluation

To determine the effectiveness of the project in reducing morbidity and mortality, we calculated two injury rates for the target area as well as for the rest of Oklahoma City: the number of fire-related injuries per 100,000 population and the number per 100 residential fires. We also calculated the rate of residential fires per 1000 homes in the target area and the rest of the city; the numerator was the number of fires that occurred in occupied dwellings according to the Oklahoma City Fire Department, and the denominator was the number of occupied homes according to the 1990 U.S. Census.

To assess whether the distributed alarms were installed, maintained, and functioning properly, firefighters conducted on-site alarm inspections at a random sample of participants' homes 3, 12, and 48 months after the initial distribution.

We used Epi Info software for data analysis and calculations of rate ratios.[12,13] We calculated incidence-density ratios using rates before and after the intervention with person-time denominators (comparing the number of cases occurring per unit of population-time — i.e., the number of person-months at risk) and confidence intervals according to the method of Kleinbaum et al.[14]

RESULTS

Surveillance

During the 32-month period from September 1987 to April 1990, a total of 66 persons in Oklahoma City were injured in 46 residential fires (annual rate, 5.6 per 100,000 population); 34 (52 percent) died. The ratio of injuries per fire was similar for the target area (1.2:1) and the rest of the city (1.4:1). Cross-referencing of discharge data from all hospitals, the records of the Oklahoma Department of Vital Statistics, the Office of the Chief Medical Examiner, and the Oklahoma City Fire Department, and newspaper clippings revealed that all injuries meeting the case definition were reported. When the cases were mapped according to the location of the fire, 30 (45 percent) occurred in the target area (Fig. 1), where only 16 percent (73,301 people) of the population lived (annual rate, 15.3 per 100,000 population, as compared with 3.6 per 100,000 in the rest of Oklahoma City; rate ratio, 4.2; 95 percent confidence interval, 2.6 to 6.9). The rate in the target area was 2.6 times higher than that in the rest of Oklahoma City (5.0 vs. 1.9 injuries per 100 residential fires; rate ratio, 2.6; 95 percent confidence interval, 1.6 to 4.5). In the target area, only 4 of the 30 fatal and nonfatal injuries (13 percent) occurred in homes with functioning smoke alarms.

Census data revealed that the target area, as compared with the rest of Oklahoma City, had a lower median household income, lower property values, and a poorer quality of housing (data not shown). The number of persons per occupied dwelling was 2.1 in both the target area and the rest of the city.

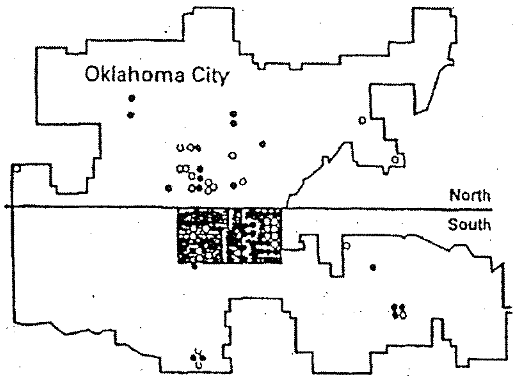

Figure 1. Map of Oklahoma City Showing the Locations of Residential Fires Causing Injury (O) or Death (●) from September 1987 to April 1990, before the Smoke-Alarm–Giveaway Program Was Initiated.

The area targeted for the subsequent intervention consisted of the four ZIP Code areas (shaded area) of the city in which 45 percent of the fires had occurred.

Implementation of the Program

Among the 1615 of 34,945 target-area homes visited by firefighters in the first home survey, 1413 (87 percent) participated. Using data gathered in this home evaluation, we estimated that 66 percent of the households in the target area had smoke alarms and that 11,881 homes had no smoke alarms.

Between May and November 1990, a total of 10,100 smoke alarms were distributed to 9291 homes in the target area; thus, 78 percent of the estimated 11,881 homes without alarms received an alarm. Program representatives installed 917 of the alarms (9 percent).

Program Evaluation

During the four years after the intervention (May 1990 to April 1994), the annualized injury rate per 100,000 population in the target area decreased 80 percent (from 15.3 to 3.1; incidence-density ratio, 0.2; 95 percent confidence interval, 0.1 to 0.4), as compared with a slight increase of 8 percent in the rest of the city (from 3.6 to 3.9 per 100,000 population; incidence-density ratio, 1.1; 95 percent confidence interval, 0.7 to 1.7) (Table 1).

Likewise, the injury rate per 100 residential fires decreased 74 percent in the target area, from 5.0 to 1.3 (rate ratio, 0.3; 95 percent confidence interval, 0.1 to 0.6), whereas in the rest of Oklahoma City the rate increased 32 percent, from 1.9 to 2.5 (rate ratio, 1.3; 95 percent confidence interval, 0.9 to 2.0). The case fatality rate in the target area decreased from 53 percent to 33 percent, while in the rest of the city it decreased from 50 percent to 41 percent; neither of these reductions was statistically significant. In the target area, none of the nine fires resulting in injury after the intervention were caused by fire play (the leading cause before the intervention).

The annual rate of fires reported per 1000 homes continued to be higher in the target area than in the rest of Oklahoma City during the four years after smoke-alarm distribution, although the rate declined in both areas. In the target area, the rate decreased 25 percent, from 6.4 to 4.8 fires per 1000 homes per year after the intervention; in the rest of the city the rate decreased 18 percent, from 3.9 to 3.2 fires per 1000 homes per year after the intervention.

Table 1. Rates of Injuries Related to Residential Fires before and after the Implementation of a Smoke-Alarm–Giveaway Program in the Target Area and the Rest of Oklahoma City, September 1987 to April 1994.

Period*	Target Area				Rest of City			
	No. of fatal injuries/ total injuries	No. of fires	Annualized injury rate/100,000 population	Injury rate/ 100 residential fires	No. of fatal injuries/ total injuries	No. of fires	Annualized injury rate/100,000 population	Injury rate/ 100 residential fires
Before the smoke-alarm program								
9/87–12/88	11/16	326	16.4	4.9	13/21	906	4.2	2.3
1/89–4/90	5/14	272	14.3	5.1	5/15	942	3.0	1.6
Total (9/87–4/90)	16/30	598	15.3	5.0	18/36	1848	3.6	1.9
After the smoke-alarm program								
5/90–8/91	0/3	237	3.1	1.3	5/15	858	3.0	1.7
9/91–12/92	1/1	183	1.0	0.5	9/20	674	4.0	3.0
1/93–4/94	2/5	249	5.1	2.0	10/23	747	4.6	3.1
Total (5/90–4/94)	3/9	669	3.1	1.3	24/58	2279	3.9	2.5
Incidence-density ratio (95% confidence interval)†			0.2 (0.1–0.4)				1.1 (0.7–1.7)	

*Equal intervals of 16 months are shown for comparison purposes.

†The incidence-density ratio compares the number of cases occurring per person-months at risk in each group before and after the intervention.

To determine whether the alarms were properly installed and maintained, 3 months after the program began firefighters visited a random sample of 9 percent of the 9291 homes (875) that received an alarm; they visited a random sample of 60 percent of homes (5617) after 12 months and 8 percent of homes (749) after 48 months. The first two surveys revealed that the alarms were properly installed and functioning in over 50 percent of the homes inspected (Table 2). During the last inspection, the proportion of occupants who had removed the alarm battery or who had moved and taken the alarm with them was higher than in the first two inspections; nevertheless, 45 percent of the alarms distributed during the program were still functioning four years later. During the four years, 182 homes that received an alarm in the target area reported fires to the fire department; no injuries were associated with these fires.

DISCUSSION

Surveillance data are the foundation of the public health approach to the prevention of diseases and injuries[15,16]; these data are frequently used to conduct epidemiologic studies and to identify high-risk populations, activities, or behavior that prevention programs could target. Although several studies identified populations at high risk for injury or death from fire, high-risk behavior (including the lack of smoke-alarm use), and fire sources that could be targeted in prevention programs,[10,17-21] there are few reports on the implementation and evaluation of a program aimed at reducing fire-related injuries.[22,23] Although smoke alarms have been proved to be effective in reducing the incidence of injuries and death from residential fires (especially fires that occur when occupants are sleeping),[11,24] we are not aware of any previous reports on the efficacy of large-scale smoke-alarm–giveaway programs.

Table 2. Functional Status of Smoke Alarms 3, 12, and 48 Months after the Smoke-Alarm–Giveaway Program.*

Smoke-Alarm Status	3 Months (N=875)	12 Months (N=5617)	48 Months (N=749)
		percent	
Alarm properly installed and functioning (95% confidence interval)	61 (58–64)	51 (50–52)	45 (41–49)
Alarm not installed	20	6	4
Alarm improperly installed	4	2	1
Alarm or battery not functioning	2	5	7
Batteries removed from alarm	2	10	19
Occupant no longer had the alarm	7	14	9
Alarm removed from house when occupant moved	4	11	15

*For each period, the number given is the number of homes included in the random sample of homes that participated in the smoke-alarm–giveaway program. Because of rounding, not all percentages total 100.

In our study, such a program reduced the incidence of fire-related injuries and deaths. The program was based on prospective, ongoing surveillance, which allowed us to focus on an area with a high rate of injuries related to residential fires and a low prevalence of smoke alarms. These data are consistent with the idea that homes that are most likely to burn are those that are least likely to have functioning smoke alarms.[17,25] The 80 percent decline in the rate of injuries in the target area after the intervention was surprising and cannot be explained on the basis of the smoke-alarm–giveaway program alone. Part of the decline in injuries may have been due to a 25 percent decrease in the number of fires per 1000 homes per year after the intervention in the target area. Educational efforts, increased awareness of the importance and prevention of the most common causes of fires in the home, and publicity about the program probably also contributed to the decline in injuries, including the decline in fire-play–related injuries. In addition, the relatively small number of injuries during this study period could have accentuated the decline in injury rates.

Ecologic studies such as this have limitations, including the unavailability of data necessary to control for confounding variables.[26] We think it is unlikely that confounders such as changes in the population prevalence of smoking or drinking or changes in weather conditions were present only in the target area and thus caused or substantially contributed to these results; there were no legislative changes directed at such potential confounders in Oklahoma City during the study period.

Because we used surveillance data to pick the area of the city with the highest rate of injury from residential fires and because of the limited period of observation, some of the decrease in the rates of fire-related injuries may have been a result of regression to the mean.[27] This phenomenon operates in such a way that for any intervention, given a specific level of program efficacy (in this case unknown), the observed effect will be higher if the base-line incidence has fluctuated by chance above its long-term average. In this instance, by picking an area of the city that had the highest rate of fire-related injuries, we would expect the rate to be reduced in subsequent years, even without an intervention. However, we believe that this phenomenon had a minor effect on our results, for several reasons. We analyzed nearly three years of data on the incidence of injury before the intervention. The sudden, marked decline in the injury rate coincided with the implementation of the intervention and persisted for at least four years. We analyzed the number of injuries per 100 residential fires as well as per population, which should minimize any potential bias introduced by the variation in temporal trends, and the number of fires per 1000 homes continued to be higher in the target area even after the intervention. In addition, the type of housing in and demographic characteristics of the target area were well known to be associated with a high risk of residential-fire-related injuries, and it seems unlikely that these factors would have changed rapidly.

The results of this study confirm that the presence of smoke alarms in homes helps prevent fire-related injuries and suggest that programs to increase their use may reduce such injuries, especially in areas identified by ongoing surveillance as having high rates of fires. The use of hard-wired smoke detectors or smoke alarms with lithium batteries (estimated to last 10 years) might lead to even greater benefit as a result of the increased longevity of such products. Interventions that target areas with high rates of fires may be especially efficient ways to lower the incidence of injuries and deaths from residential fires.

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AN ANALYSIS OF THE PERFORMANCE OF RESIDENTIAL SMOKE DETECTION TECHNOLOGIES UTILIZING THE CONCEPT OF RELATIVE TIME

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ABSTRACT

Since the inclusion of smoke detectors in residential fire safety plans, several experimental studies have been undertaken to evaluate the effectiveness of the most common types of residential smoke detectors: ionization, photoelectric, and combination. The most notable studies are the NIST Indiana Dunes tests from the 1970s [1], and the more recent 2003 NRC Canadian Kemano [3] and NIST Dunes 2000 studies [4]. A common problem when evaluating smoke detector technology performance from these and other studies is that the fires and smoke sources can vary from test to test. Likewise, detector locations, test geometries, and fire locations often vary from study to study. Due to these variations in fire growth and smoke concentration and velocity at different detector locations, smoke detector activation times have been comparable only for detectors used in the same test and sited at the same location. Comparisons across a broader range of experiments and locations have been difficult at best.

This study introduces a new concept for the evaluation of the effectiveness of smoke detector technologies. This new analytical technique utilizes a non-dimensional relative time, where the activation time of a smoke detector in a specific test is normalized based on the activation time of the first detector to alarm at that location in that particular test. Utilizing this technique permits the researcher to account for different fire development times among the various flaming and smoldering fire studies. By normalizing the activation times in this manner, the test-specific variables no longer influence the comparison, and results from several tests can be compared simultaneously to determine overall trends. This normalization leaves only the type and sensitivity of each smoke detector as the relevant variables. The results of the Dunes (1970s), 2003 Kemano, and Dunes 2000 tests have been analyzed using this new relative time methodology. In total, 2,843 data points were analyzed in this manner.

These three fire studies were first evaluated individually. For each test, photoelectric, ionization, and combination detectors were assigned to a group based on their placement in the building. For example, all of the detectors on the ceiling of a certain room were considered one group. Typically, each cluster contained a variety of detector types, although there were occasional exceptions. The first detector in each group to react to the test fire was noted, and each individual detector's relative time to activate was then found by dividing its absolute sounding time by the absolute time of the first detector to sound in that particular group:

$$t_{act,rel} = \frac{t_{act,abs}}{t_{act,abs,first}}$$

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Utilizing this methodology, the detector in each group that first activated will have a relative time of one, while the group's other detectors will have relative times exceeding one. By looking at the relative time of each detector instead of the absolute time, results from several studies and tests can be compared while eliminating differences such as fire growth rate or detector location. Thus, instead of examining the performance of any one detector, the relative performance of a detector compared to other detectors under the same conditions is examined. For example, the relative times from a specific smoldering test from the Kemano study are shown below as Figure 1.

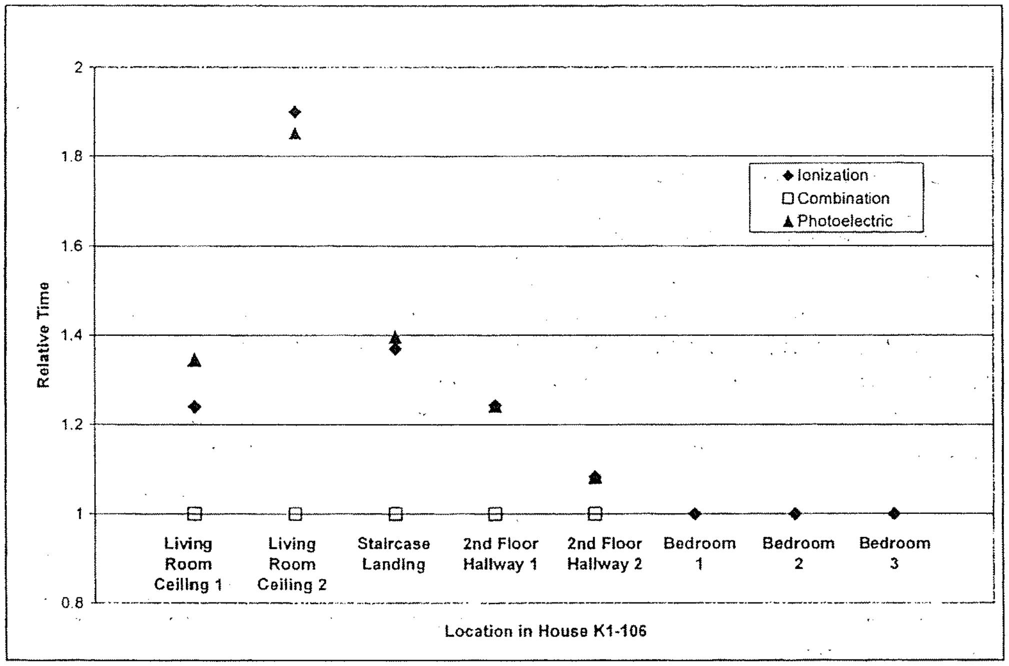

Figure 1. Relative time results for a smoldering fire that transitioned to flaming (Kemano [3] Test 12).

After each test from these three studies was analyzed in this fashion, the results were consolidated into 3 categories based on fire type: smoldering, flaming, and kitchen. The average relative time to detector activation for each type of detection technology was calculated, and a 95% confidence interval (i.e., two standard deviations) was determined and plotted. Data that were not within three standard deviations of the average were omitted, since these results were often found to be caused by data acquisition errors. These errors were confirmed from test data of the monitored voltage of the detector or from test notes from the experimental team, thereby justifying the omission of the data outside three standard deviations. Likewise, activation times from any detectors that activated in a manner very inconsistent with other detectors at a given location or in an obviously erroneous way were not considered, because this data skewed the results. These errors occurred most often in the Dunes 2000 tests, where the monitored voltages showed considerable noise. In many cases, this electrical noise inferred detector activation, based on the NIST protocol, even though smoke had not yet arrived at the detector location. The plots of the data for the three types of fires, smoldering, flaming, and kitchen, are shown below as Figures 2-4.

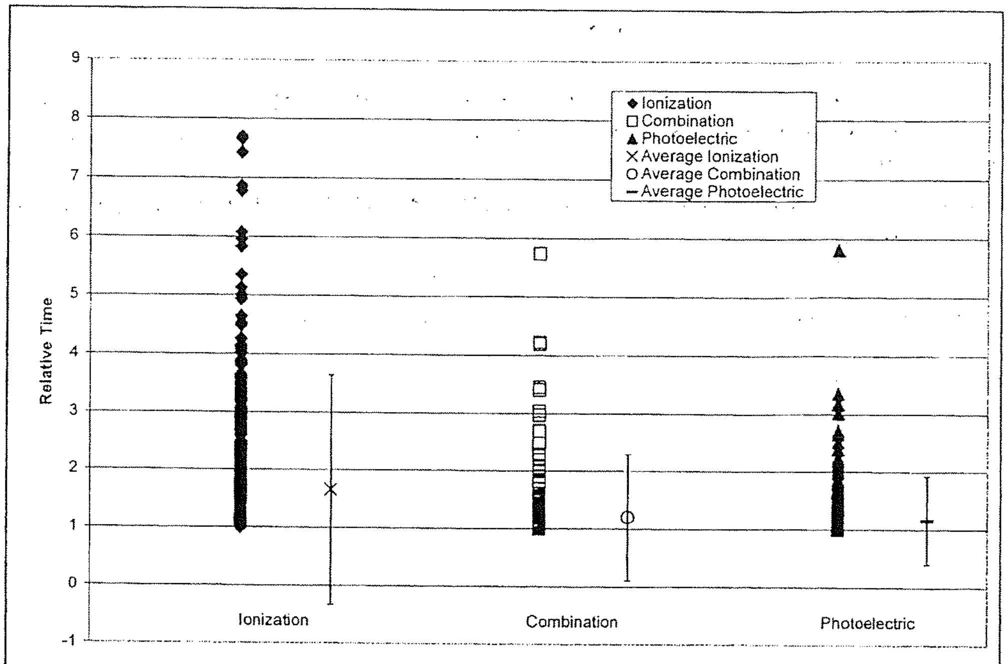

Figure 2. Relative time data for all of the smoldering tests from the Dunes [1], Kemano [3], and Dunes 2000 [4] studies. The average value and the 95% confidence interval for the different detection technologies are also shown.

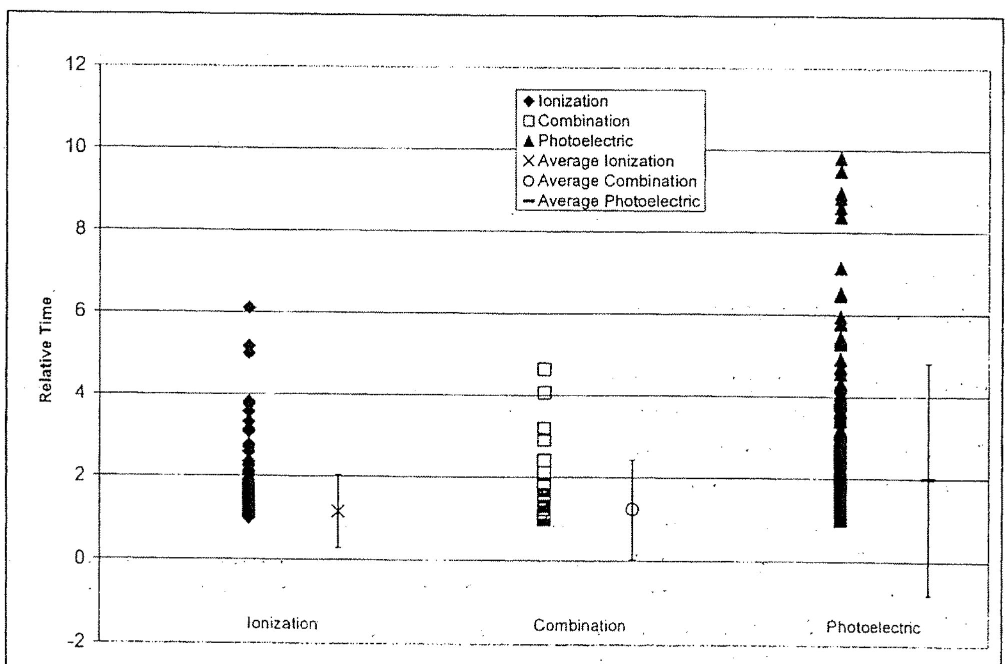

Figure 3. Relative time data for tests using the flaming fires from the Dunes [1,2], Kemano [3], and Dunes 2000 [4] studies. The average value and the 95% confidence interval for the different detection technologies are also shown.

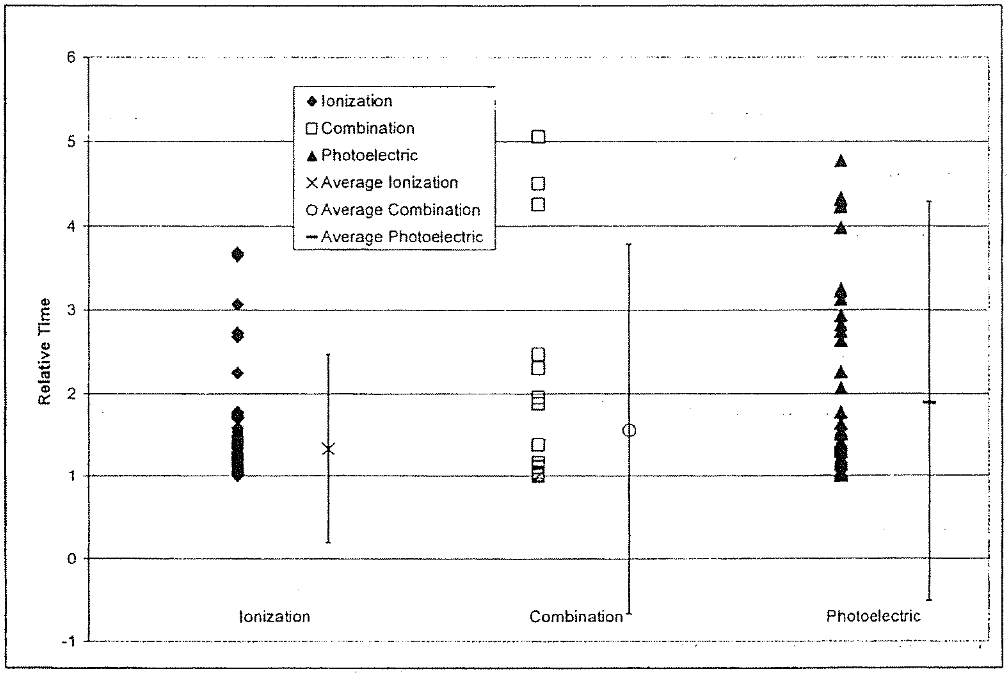

Figure 4. Relative time data for kitchen fire tests from the Dunes [1 2], Kemano [3], and Dunes 2000 [4] studies. The average value and the 95% confidence interval for the different detection technologies are also shown.

As can be seen from the figures above, this study found that ionization smoke detectors are generally faster at responding to flaming fires, and photoelectric smoke detectors are generally faster at responding to smoldering fires. This conclusion, based on the average of the relative times for both types of detectors and both kinds of fires, is in agreement with the conclusions of previous studies. Ionization detectors were also faster at detecting kitchen fires. While this generality that ionization detectors are faster at detecting flaming fires and that photoelectric detectors are faster at detecting smoldering fires was confirmed, this study determined that overall there is no statistically significant difference between the activation time of ionization and photoelectric detectors when the entire data set is considered.

This conclusion that there is no statistically significant difference in the activation times of ionization and photoelectric detectors is based on the small difference in their average response times when compared with the considerable overlap of the confidence intervals of the data. This finding demonstrates that while one detection technology may on average be slightly better than another for a particular type of fire, there is no statistically significant difference between the detection technologies. Hence, for a fire of any given type, there is no statistical guarantee of which type of detector will detect that fire first. Therefore, this analysis shows that ionization, photoelectric, and combination technologies are essentially equivalent for the detection of household fires.

This finding is not surprising, because identical testing requirements are placed on all smoke detection technologies. All detectors, regardless of what detection technology is used, must pass UL 217 [5] or UL 268 [6], and thus should have similar detection capabilities across all fire types. Figure 5, presented below, shows the relative time performance of the three detector types to all types of fires for both the Dunes testing in the 1970s and the more recent Dunes 2000 testing. Note that the average activation times for the different technologies are quite similar for both data sets. This figure indicates that the relative performance of ionization and photoelectric technologies has not changed significantly over the past 35 years, since there was not and still is not any statistically significant difference in the performance of ionization, photoelectric, or combination detectors. Therefore, the conclusions of the original Dunes testing of the 1970s that either ionization or photoelectric detectors provide adequate warning for most household fires still have application today. These conclusions endure even though fuel types have changed and absolute activation times and provided escape times may have been reduced.

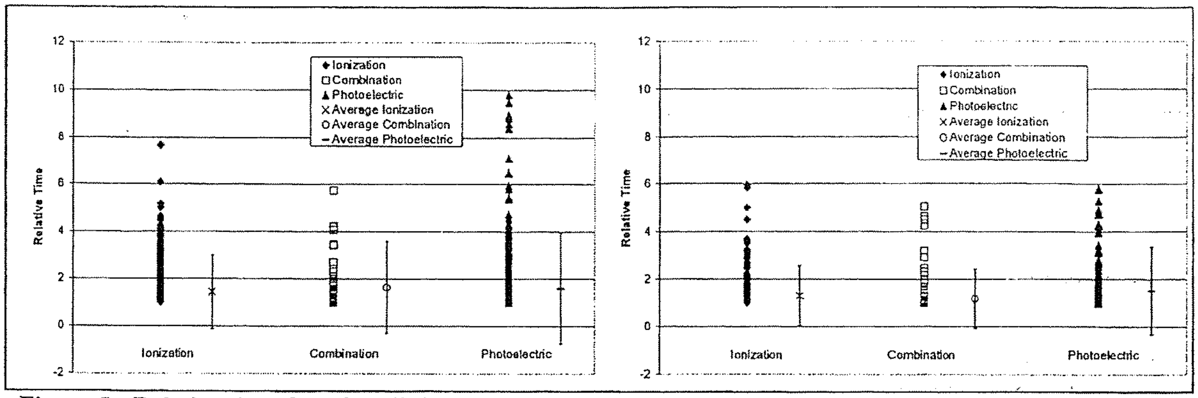

Figure 5. Relative time data for all the fire tests for the Dunes tests (1970s) (left) [1,2] and the Dunes 2000 tests (right) [4]. The average value and the 95% confidence interval for the different detection technologies are also shown.

Furthermore, this study found that ionization detectors showed greater scatter in detection time of smoldering fires, and photoelectric detectors showed greater scatter in detection time of flaming fires. This result can be seen in the variability of the data and in the magnitude of the confidence intervals in Figures 2 and 3 above. In addition, combination detectors were found to offer no statistically significant better performance than an ionization or a photoelectric detector singularly, regardless of fire type. Combination detectors, though, showed less scatter in detection time than either ionization or photoelectric detectors. Despite this minimal advantage, combination detectors inevitably will have more false alarms, since they will alarm to nuisance sources for both ionization and photoelectric detectors. This potentially negative aspect of combination detectors was not explicitly considered in this study.

Finally, the data from all of the fire types was combined into one comprehensive graph, which is shown below as Figure 6. When the data for each given detector type is averaged, it becomes apparent that all the detection types are statistically equivalent at a 95% confidence level. In practice, this means that if the next fire type is unknown, as will generally be the case, ionization and photoelectric detectors are, on average, equivalent for detecting the fire. Moreover, even if the next fire is known, consumers can be confident that they will be getting equivalent performance compared with other detection technologies regardless of what type of detector is installed. Combination detectors performed slightly better on average than either the ionization or the photoelectric detectors, but again, unless the detection chamber signals are combined with computer algorithms (e.g., the response of one chamber is used to confirm the response of the other), which would change the relative time results, the combination detector will be more prone to false alarms.

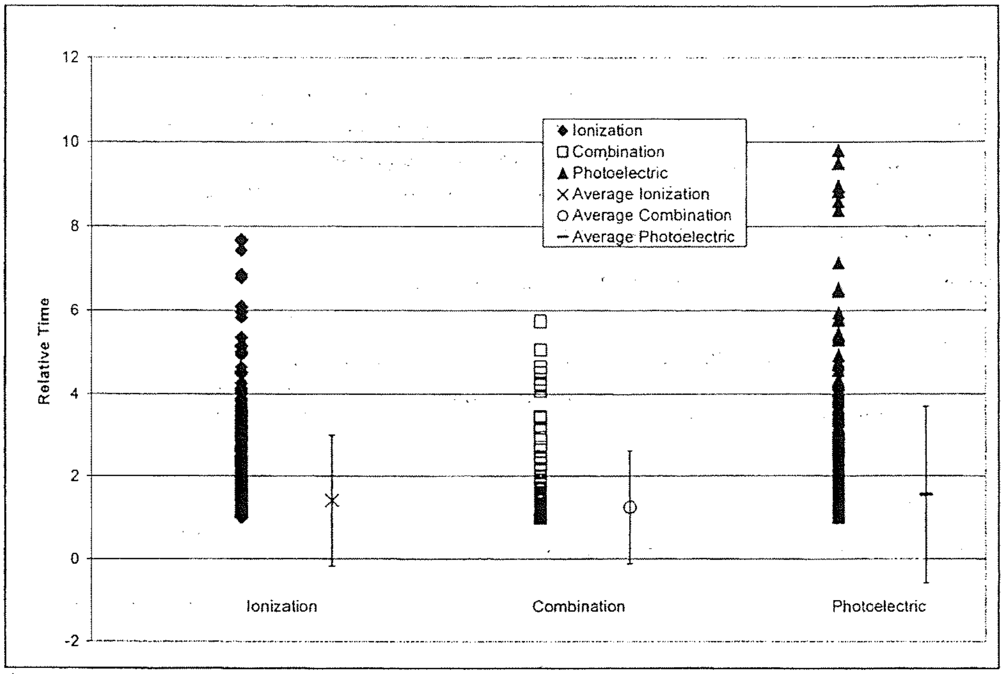

Figure 6. Relative time data for all tests from Dunes [1], Kemano [3], and Dunes 2000 [4]. The average relative time for each detection technology is also shown, along with the 95% confidence levels. The total number of data points analyzed was 2843.

In summary, this study demonstrates that ionization, photoelectric, and combination detectors provide statistically equivalent warning to different types of fires. This finding holds for the Dunes studies in the 1970s, and still holds today for the 2003 Kemano and Dunes 2000 studies, showing there has been no noticeable increase in the effectiveness of one type of detector over another in the last 35 years. This conclusion is still valid even as different furnishings have been introduced into the market and as other changes in residential fire hazards have occurred over this time period. The results from this study clearly show that instead of continuing to debate which technology is currently better, installation efforts should emphasize maximizing the number of detectors in residences. Similarly, research efforts should be focused on lowering the absolute time for activation of all detectors while decreasing false alarms through nuisance source rejection. By focusing on reducing time to activation and on reducing false alarms, relative time will effectively remain unchanged, but overall fire safety for occupants of a residence will be increased.

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